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(NASA-CR-169751) ANTI-MISTING ADDITIVES FOR
JET FUELS Final Technical Report, 1 Jan. -
30 Sep. 1982 (California Univ.) 10 p
HC A02/MF A01

CSCL 21B

N83-16417

Unclass

G3/25 02472

Final Technical Report

ANTI-MISTING ADDITIVES FOR JET FUELS

Supported by a Cooperative Agreement between NASA-Ames Research Center
and the Regents of the University of California.



Agreement No. NCC 2-164

Agreement Period Jan. 1, 1982 - Sept. 30, 1982

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SUMMARY

The ignition characteristics of sprays, created by wind-shear action, of Jet-A fuel containing polyisobutylene additives were examined over ranges of air velocities from 45 to 90 m/s and of fuel/air mass ratios of 0.20 to 8.0. Ignition was by calibrated sparks of energies up to about 0.5 J and by a butane/oxygen flame at 165 J/s. The polymeric additives studied included the grades L80, L160, and L200 from Exxon Chemical and B200 and B230 from BASF.

The ignition suppression ability of the additives, as well as their observed anti-misting (AM) behavior, ranked exactly as their molecular weights (viscosity average, M_v) with 400-500 ppm of L80 ($M_v = 0.68 \times 10^6$) being required to suppress ignition of a spray at 51 m/s, 1.8 fuel/air mass ratio, by a 0.55 J spark while only 10 ppm of B230 ($M_v = 7.37 \times 10^6$) was required for the same conditions. The additive concentrations (L160) required for ignition suppression increased with increasing air velocity and with increasing fuel/air ratio, the latter effect being very pronounced at ratios below about 3 and becoming much less significant at higher ratios. The concentrations (L160) required to suppress ignition by the 165 J/s flame were only about 50%-75% higher than those required for ignition by the 0.55 J spark.

BACKGROUND

Fires during jet aircraft crash-landings can be suppressed by addition of small amounts of polymeric solutes to the jet fuel.¹ Studies of this phenomenon indicate that the additives inhibit the formation of fuel mists upon impact and rupture of fuel tanks²⁻⁴; thus they are called antimisting (AM) agents. The use of such agents in commercial aircraft operations has the potential to reduce the loss of lives in post-crash aircraft fires.

The mechanism by which these AM additives function has not been completely explained. They directly influence the rheological properties of the additive/fuel solution, including both shear and elongational viscosity. These rheological properties, in turn, affect the fuel break-up into mists under wind shear or impact. The presence of additives gives rise to sprays composed of unusually large and frequently nonspherical, often filamentous, droplets⁵⁻⁷. The ignitability of such sprays is suppressed because of the reduced droplet surface area in the sprays and the increased distances between droplets, but a much better understanding of these processes will be required before the effectiveness of AM agents can be predicted from models of the spray phenomena.

The development of effective AM agents can be guided by the correlation of AM and ignition-suppression abilities of additives with their

molecular characteristics and with the rheological properties of their solutions in jet fuel. Such correlations, together with qualitative explanations of the mode of action of the agents, have shown that the AM effectiveness of the polymers can be related to the elongational viscosity of their solutions in the fuel, as measured by the "durtless siphon" performance of these solutions.⁷ It was also found that this elongational viscosity, and thus AM performance, increased with increasing molecular weights of the polymers (chain length) and with better compatibilities of the polymers with the solvents. The observed AM performance was directly related to suppression of ignition by sparks over a wide range of flow conditions. Work conducted by Kapelke⁸ showed similar rankings of additives for flammability reduction of Jet-A fuel using a test apparatus developed by the F.A.A.⁹ However, certain difficulties with that apparatus made quantitative interpretation of the results difficult.

Therefore, a further examination of the effect of spray conditions and ignition method was undertaken in the present work. The objective was to determine the effect of air velocity, fuel/air ratio (fuel flow rate), and flame vs spark ignition on the levels of several polyisobutylene additives (supplied by NASA) required to suppress ignition of Jet-A fuel sprays created by wind-shear action. At the same time the associated problems of the pumpability (viscosity) of the solutions, particularly at low temperatures, were addressed in a related research program, NCC 2-163.

EXPERIMENTS

Materials. The polymeric AM agents used in this work were five linear polyisobutylenes (PIB): three Vistanex grades (L80, L160, L200) from Exxon Chemical, and two Oppanol grades (B200, B230) from BASF. These were all characterized as to molecular weight distribution by GPC in our previous work.⁷ Their number-, viscosity-, and weight-average molecular weights (M_n , M_v , and M_w , respectively) are listed in Table 1.

The solvent used was Jet-A fuel obtained from Shell Oil Company at Oakland, California Airport. It had a density of about 0.80 g/cm³ and a vapor pressure of about 5000 Pa at 20°C. All solutions were prepared by slow dissolution of finely divided solid polymer under gentle stirring in flasks in a warm water bath. Stock solutions prepared at 3000 ppm were subsequently diluted to obtain other concentrations.

Apparatus. Studies of flammability were conducted in a relatively small-scale apparatus in which sprays are created by wind-shear action of an air jet passing horizontally over the end of a vertical tube through which fuel is supplied at a controlled rate. This apparatus, shown schematically in Figure 1, consisted of an atomizer for formation of the spray, a secondary air supply for variation of air-to-fuel ratios, and an observation and ignition chamber for studies of the sprays.

In the atomizer, fuel was supplied to a vertical, 1.0 mm ID, tube by a calibrated syringe pump. Primary air from a 1.75 mm ID nozzle was directed horizontally across the end of the fuel supply tube as shown in Figure 1; this primary air was supplied from a compressed gas cylinder through a regulator, a rotameter, and needle valve for control of its flow. The atomizer was positioned concentric to, and 4.5 cm downstream from, the end of a 2.5 cm ID secondary air supply duct fed by a centrifugal blower; however, secondary air was not used in this study.

Spray from the atomizer was directed into the 38 cm square by 66 cm long observation chamber, which discharged at its downstream end into a laboratory fume hood and was otherwise enclosed, except for the centrally located 2.5 cm entry for the atomizer/secondary air duct on the upstream end. This chamber was fitted on both sides with 6.4 x 20 cm quartz windows for spray observation, with electrode holders for a spark ignition device, and with a flame igniter.

The apparatus was capable of spraying fuel at rates of 4 to 77 cm³/min with primary air velocities of 20 to 90 m/s (45 to 201 mph). Fuel-to-air mass ratios of 0.2 to 8 could be obtained.

Flammability was usually tested by electrical spark discharge between tungsten alloy electrodes spaced 5 mm apart and placed horizontally across the spray at its centerline and 5.5 cm downstream from the atomizer. Sparks were produced by an electronically triggered capacitor discharge device, operating at 15 kV, and able to produce sparks of 0.1 to 0.55 J at repetition rates up to 2 s⁻¹. The spark energies for this device were controlled by capacitor switching and were calibrated from simultaneous oscilloscope traces of spark voltage and current.

Additional flammability tests were made with ignition provided by a butane/oxygen flame. The flame igniter consisted of a 0.21 cm ID tube directed concurrent with, and centered in, the spray with its end located 5.5 cm downstream from the atomizer tip, as shown in Figure 2. A pre-mixed stoichiometric butane/oxygen mixture was supplied to this tube through flow meters and metering valves from gas cylinders. The flame energy could be controlled from about 150 to greater than 400 J/s.

RESULTS AND DISCUSSION

The relative effectiveness of the PIB additives examined here was evaluated in terms of the concentrations required to prevent ignition by a 0.55 J spark of a spray created at an air velocity of 51 m/s and fuel-to-air ratio of 1.8 (about 27 times stoichiometric). The required AM agent concentrations ranged from 500 ppm for L80 to only 10 ppm for B230, as shown in Table 1. The ranking of the polymers was exactly in the order of their viscosity- (or weight-) average molecular weights, for this homogeneous series. The large shifts in required additive concentrations for relatively small average molecular-weight differences indicates that the high molecular-weight "tail" of the distribution probably has a dominating influence on AM action.

The relative rankings of AM agents found here were exactly the same as those found by Kapelke⁹ for L160, B200, and B230 (the only PIB's he tested) using the FAA flammability test apparatus. Those tests used flame ignition, air velocities of 50 to 90 m/s, and fuel flows of 7 to 14 cm³/s, and based flammability ratings on heat flux from fixed positions in the flame area.

The effect of spray conditions in the present work was examined for air velocities of 60 to 90 m/s and fuel/air ratios of 1 to 6 (15 to 90 times stoichiometric). The polymer concentrations required to suppress ignition by a 0.55 J spark generally increased with increasing air velocity and, at least at lower fuel/air ratios, with fuel/air ratio, as shown in Figure 3 for L160. With regard to flammability dependence on fuel/air ratio (or fuel flow rate) a saturation behavior was evident, as can be seen in the figure, with flammability increasing rapidly with fuel/air ratio at lower ratios and only slowly, or not at all, at higher ratios. It certainly appears that increasing fuel flows beyond those examined here, particularly at higher air velocities (more severe conditions), would not lead to significantly more flammable sprays, at least for ignition by 0.55 J sparks.

The relative effectiveness of flame vs spark ignition, under the same spray conditions, has also been examined, although this comparison has been limited to L160 solutions by the restricted duration of this program. The flame size, at least for flames of at least 165 J/s, had no discernible effect on spray ignition, with the same AM agent concentrations being required to suppress ignition by 350 J/s and 165 J/s flames. Somewhat higher L160 concentrations were required to suppress flame ignition than 0.55 J spark ignition, but the changes were not great, being about a 50 to 75% concentration increase. For example, at an air velocity of 67 m/s, fuel/air ratio of 3.2, about 250-300 ppm of L160 was required to prevent flame ignition while 160 ppm was sufficient to suppress 0.55 J spark ignition. Flame ignition results are considerably less reproducible than those using spark ignition, owing to the impacting of spray particles on the tube that supports the flame and the variable accumulation and movement of this impacted material.

CONCLUSIONS

The study of ignition properties of Jet-A fuel with PIB additives as anti-misting agents has shown that these additives rank in effectiveness according to their viscosity-average molecular weights, and with higher molecular-weight grades such as B230, can be very effective in suppressing ignition of wind-shear created fuel sprays at concentrations well below 100 ppm. The ranking of these AM agents is independent of spray conditions and source of ignition.

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TABLE 1
PROPERTIES AND PERFORMANCE OF AM AGENTS (PIB)

| | <u>Molecular Weight $\times 10^{-6}$</u> | | | <u>Concentration Required to Prevent Ignition by 0.55 J Spark*</u> |
|--------------|---|-------------|-------------|--|
| | \bar{M}_n | \bar{M}_v | \bar{M}_w | |
| Vistanex L80 | 0.65 | 0.77 | 1.75 | 400 ppm |
| L160 | 1.4 | 4.11 | 5.04 | 65 |
| L200 | 1.1 | 5.00 | 5.37 | 32 |
| Oppanol B200 | 1.4 | 5.70 | 6.02 | 22 |
| B230 | 1.1 | 7.37 | 9.00 | 10 |

*Wind-shear created spray with air velocity = 51 m/s, fuel/air mass ratio = 1.8

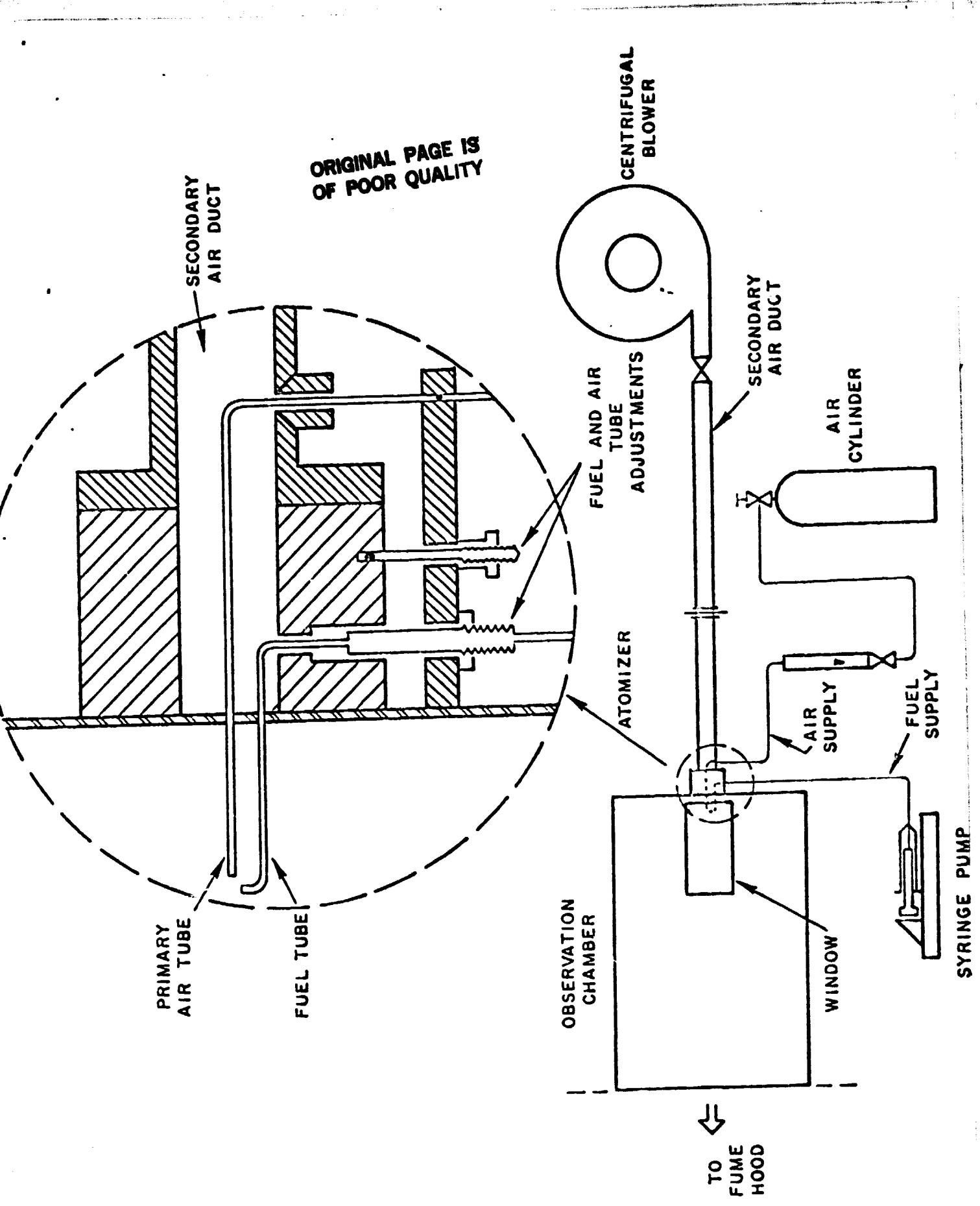


Figure 1. Spray creation apparatus

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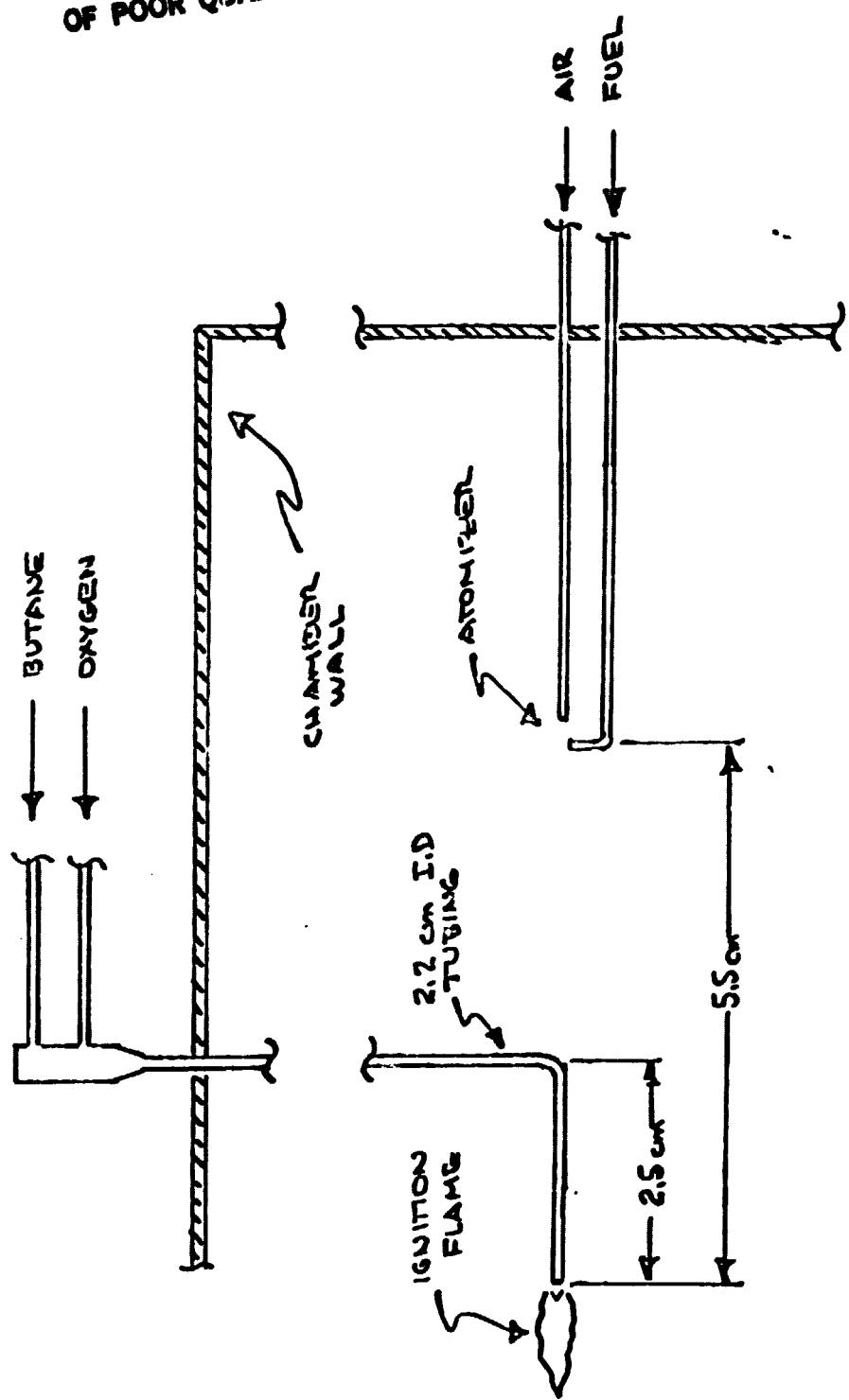


Figure 2. Flame ignition device

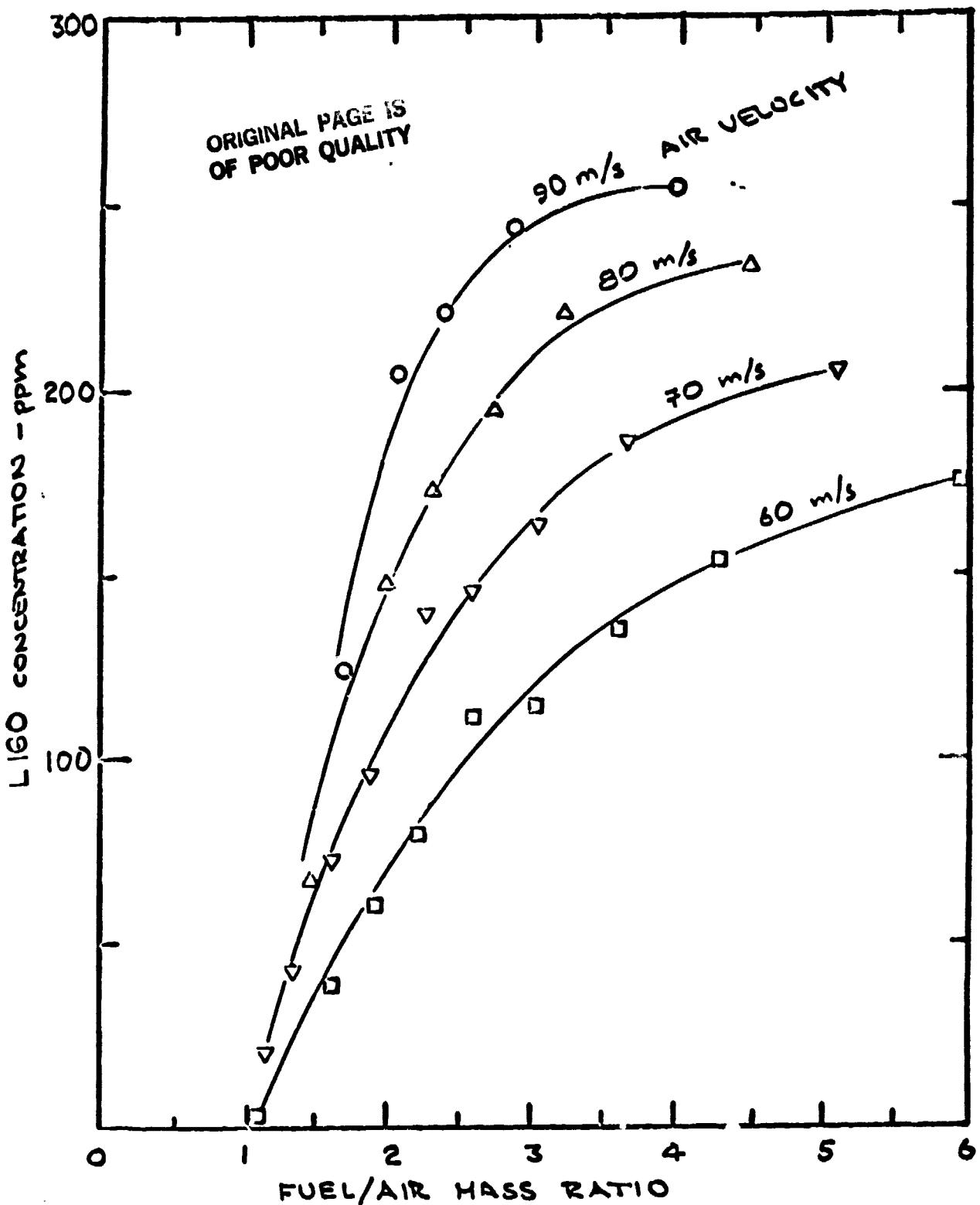


Figure 3. Effect of fuel-air ratio on flammability of Jet-A sprays containing L160 additive at several air velocities. Flammability measured as L160 concentration required to suppress ignition by 0.55 J spark.